Performance Evaluation of 2-channel Embedded Infrared Fiber-optic Temperature Sensor

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1. Introduction

In general, resistance temperature detectors (RTDs) and thermocouples (TCs) are widely used to measure temperature in industrial settings. However, there are difficulties in accurately measuring temperature using existing electrical sensors due to contamination or corrosion of the sensing probe and high electromagnetic interference (EMI) or radiofrequency interference (RFI) in harsh environments.

Alternatively, optical fiber-based sensors may be used to measure physical properties including a temperature. These sensors offer many advantages over conventional electrical sensors, including small size, good flexibility, remote sensing, immunity to EMI or RFI, and resistance to harsh environments. Generally, it is possible to determine the temperature of any warm object by measuring the emitted infrared (IR) radiation [1,2]. The operating principle of a radiometer using IR optical fiber is based on the relationship between the surface temperature of a heat source and the quality and the quantity of IR radiation [3]. The intensity (I) of emitted IR radiation depends on the temperature (T) of the heat source [4], as delineated in equation 1.

$$I = \varepsilon \sigma_e T^4 \qquad (1)$$

where, ε is the emissivity of the heat source and σ_e is the Stefan-Boltzmann constant for radiant exitance, that is, 5.67×10^{-12} [W / (cm^2 K^4)]. In this case, however, a non-contact radiometer can only measure the surface temperature of a heat source, and the output signal of the radiometer is influenced by the emissivity variation in accordance with the surface conditions of the heat source. Therefore, it is necessary to develop a new concept for IR fiber-optic temperature sensors that circumvent emissivity effects of the measured heat source and are independent of ambient temperature variation.

2. Materials and Experimental Setup

As IR optical fiber, a silver halide optical fiber (JT Ingram, PIR 900/1000) is selected for this study. The outer diameter of this IR optical fiber is 1.0 mm, and the cladding thickness is 0.05 mm. The refractive indices of the core and the cladding are 2.15 and 2.13, respectively, and the numerical aperture (NA) is 0.25. The silver halide optical fiber is transparent in a wide spectral range from 4 to 18 μm. This optical fiber is very flexible and durable over a temperature range from -200 to 250℃, and its melting point is 415℃.

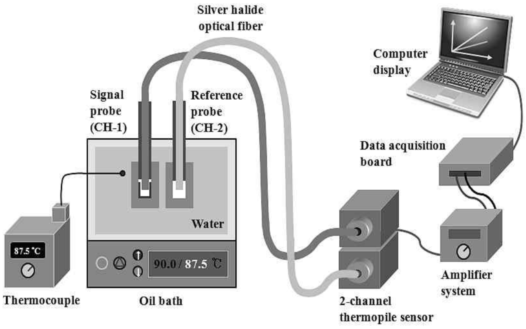

Fig. 1. Experimental setup for measuring the temperature of the water using the embedded IR fiber-optic sensor.

Figure 1 shows the experimental setup for measuring the temperature using the embedded IR fiber-optic sensor. A temperature sensing probe is composed of a cap, a tube, a silver halide optical fiber, and an IR emitting material. The cap and the tube are made of stainless steel to protect the optical fiber from the water-chemistry and harsh environment. The temperature sensing probes were divided into a signal probe (CH-1) and a reference probe (CH-2). The inner part of the cap of the signal probe was coated with high emissivity black paint ($\varepsilon \simeq 1$) as an IR emitting material while that of the reference probe was covered with a polished stainless steel cap having a low emissivity ($\varepsilon \simeq 0.1$) [4].

The signal and the reference probes and a K-type thermocouple (Fluke, 54II thermometer) were placed in an oil bath (Samheung Energy, SH-OILWB 10) with a temperature uniformity of ± 0.5℃. Each probe is connected to a 2-channel thermopile-amplifier system, which is composed of two identical thermopiles (Perkin Elmer, A2TPMI334OAA060) and an amplifier system. The thermopile can measure IR radiation at room temperature, and its sensing range is from 2 to 22 μm. The temperature of the water is determined by measuring the intensity difference of IR radiation emitted from two types of IR emitting materials in the caps. We measured the differences between the amounts of IR radiation emitted from the signal and the reference probes through repeated and random experiments.

3. Results

To calibrate the thermopile, each channel response of the 2-channel thermopile sensor was measured using the same reference probes. Figure 2 shows the output voltages of two channel thermopiles versus the temperature of the water, which is measured using a thermocouple. Although the gains and the offset voltages of each channel were similar, the two channels were corrected to be equal with a calibration procedure based on the LabVIEW program to accurately measure the temperature.

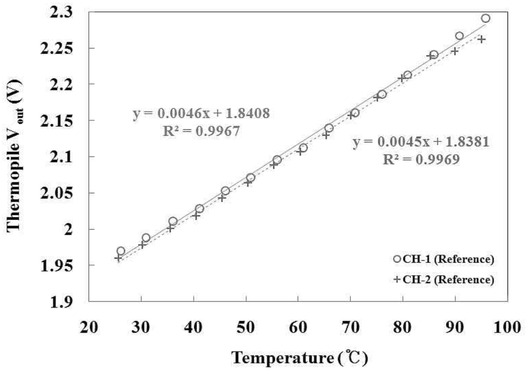

Fig. 2. Response measurements of the 2-channel thermopile sensor using the same reference probes for calibration.

Figure 3 describes the relationship between the temperature of the water and the difference in the IR signal between the two channels. The difference between two IR signals increased as the temperature of the water increased, because the difference in the output voltage between CH-1 and CH-2 gradually increased according to the temperature of the water. It is shown that there is a linear dependence between the difference in the IR signals and the water temperature, and the mathematical form of the best fit line to the curve is also presented in figure 3.

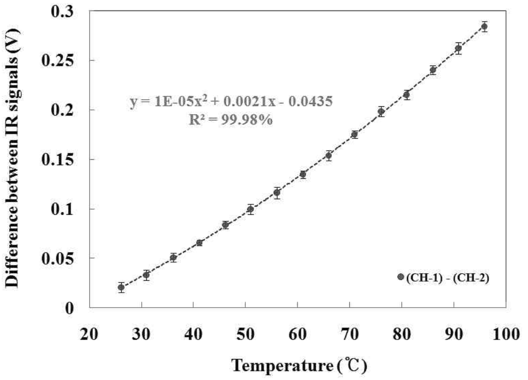

Fig. 3. Relationship between the temperature of the water and the difference in IR signals between CH-1 and CH-2.

Figure 4 shows the real-time temperature monitoring of the embedded IR fiber-optic temperature sensor to measure response time and reproducibility. In this test, response time of less than 50 second was measured at a temperature range between 26 ± 0.5 and 90 ± 0.5℃ and the sensing time per degree Celsius could be calculated as 0.78 sec/℃. In addition, the proposed temperature sensor also has good reversibility and reproducibility, with a percentage standard deviation of 0.587% at 90 ± 0.5℃, as shown in figure 4.

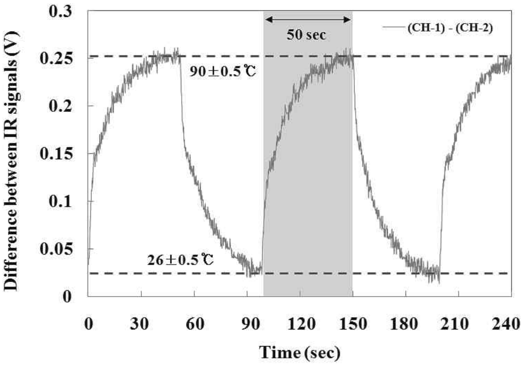

Fig. 4. Response time and reproducibility of the embedded IR fiber-optic temperature sensor.

4. Conclusions

In this study, we demonstrate that temperature can be determined according to the difference between the amounts of emitted IR radiation from the caps of individual probes, and this approach makes it possible to circumvent the emissivity effect of the measured surface of the heat source. Therefore, thermometry with the proposed sensor can have a high signal-to-noise ratio (SNR), and is immune to variation of parameters such as offset voltage, ambient temperature, and the emissivity and physical conditions of any warm object.

Further studies will be carried out to measure temperature in a high pressure/temperature environment by using an autoclave. Based on the results of this study, it is expected that a 2-channel IR fiber-optic sensor can be developed to accurately monitor temperature in harsh environments including a nuclear power plant.

ACKNOWLEDGMENT

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